

TDOA-Based Localization System with Narrow-band Signals

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Abstract—This paper gives a general overview of the challenges that arise in using narrow-band signals, such as GSM, for localisation based on the time properties of the signal. Specifically, synchronisation and retrieving of time information are addressed. We pursue two contributions, namely, analysis of achievable synchronisation precision and processing of narrow-band signals that can enable localization down to a meter.

Keywords-localization, narrow band signals, TOA, TDOA

I. INTRODUCTION

Indoor localization has turned into a field of research densely populated with studies covering a large range of technologies, system designs and localization algorithms. Simply adopting outdoor solutions is not feasible but it is possible to adapt existing algorithms for outdoor positioning to cope with the specifics of indoor environments. Our work aims to adapt the Time Difference of Arrival (TDOA) technique to work with GSM signals and, subsequently, to improve its performance indoors.

In a nutshell, the final localisation system should (i) deliver high accuracy, e.g., down to a meter, (ii) not need participation of the user and (iii) be easily portable. Therefore, we need to design a passive system that can determine a device's location by only overhearing its radio traffic. TDOA was chosen since it meets the first two requirements. However, as others are actively looking at its use with wide-band (UWB) signals, we decided to work with narrow-band signals (and GSM in particular) for their ubiquitous availability. UWB systems are not yet wide-spread and WiFi systems still depend on the user to enable the interface.

The main challenge of our approach is to ensure correct timing of the narrow-band signal. Its long pulse time leads to (i) more difficult time recovery and (ii) higher sensitivity to time shifts caused by propagation conditions. Resulting time discrepancies, are even if minor, given the high signal velocity, can lead to significant distance errors. Portable systems further increase the complexity by the processing limitations of the hardware.

Next, after a brief introduction of the system design and the localization algorithm, we discuss the challenges related to using narrow-band signals and how we plan to approach them.

II. SYSTEM DESIGN

A network-based approach, where nodes at known positions (anchors) locate a target device, is very appropriate to realize a passive system such as ours. In order to locate GSM users the anchor nodes should be able to capture GSM uplink traffic and process it to derive time references. This requires complicated signal processing, for which reason we chose for a Software Defined Radio (SDR) system. In particular, we selected the Universal Software Radio Peripheral (USRP) from Ettus, the networked N210 and embedded E110 versions. Hardware processing is realized by a daughter and mother board, while software signal processing is done on either personal computer (with N210) or embedded devices (with E110). Working on the networked device gives more freedom at early development, while the embedded device is stand-alone and fits for a portable system.

III. LOCALIZATION ALGORITHM

We decided on a localization algorithm that interprets signal propagation time to derive coordinates and has previously shown high potential for accurate positioning. Since we aim to develop a passive system, TDOA was preferred to the Time of Arrival (TOA) and Round Trip Time (RTT) methods. TOA needs participation of the target device in order to determine a sending timestamp and to synchronise with it. With RTT, synchronisation is not necessary since each anchor node calculates propagation time from the total round trip time to the mobile device. Again participation of the user is required and the processing delay at the device is difficult to measure exactly since it may vary per node and time instance.

On the contrary, in the TDOA technique the distances can be calculated by overhearing of signals. TDOA measures the difference in arrival times at the anchors and, by a set of hyperbolic equations, determines the corresponding distances. The method decreases the requirement for synchronization to time-aligning only between the anchor nodes.

IV. CHALLENGES OF TDOA WITH NARROW-BAND SIGNALS

Based on our preliminary theoretical analysis and practical tests we identified two main challenges, described below, related to the use of TDOA with narrow-band signals.

A. Synchronization

Realizing highly accurate synchronisation in practise is still very challenging. In the Internet domain, the Network Time Protocol (NTP) [3] can provide an accuracy only in the order of milliseconds. In Wireless Sensor Networks (WSN), the Reference Broadcast Scheme (RBS) [2] uses a reference node to periodically broadcast a beacon packet for synchronization but it introduces an additional node and extra wireless traffic.

Despite the higher system cost, we use GPS signals for synchronization because of their high potential to satisfy the needs of TDOA. Each USRP has attached a GPS receiver, which locks to the Pulse-Per-Second (PPS) signal from a satellite. A PPS signal normally has a rising edge aligned with the GPS second and thus can be utilized to synchronize the sample time across devices. The 10 MHz clock output of the GPS receiver is used by the USRP as an external reference clock with long-term stability.

In terms of synchronisation we see our contribution in providing the research community with investigations on clock drift between devices. Our initial measurements with two collocated USRP receiving devices show that, if the internal Temperature Compensated Crystal Oscillators (TCXO) are used, the clock drift would be $0.2\mu s$ per second but, if external GPS-based clock is taken, there is no long-term clock drift.

B. Extraction of Signal Timing

Although there are studies such as [5] that propose how GSM signals can be used with TDOA for indoor localization, no evaluations with real systems are available. The main challenge is to precisely calculate TDOA, given the signal has relatively long pulse duration, which is more vulnerable to time errors. We aim to bridge the gap between theory and practise by implementing our solution in a real system and testing the achieved accuracy.

We consider two approaches to determine the TDOA between two anchors. The first approach uses the misalignment of the pulse shapes at the two nodes, see [1]. As shown in Figure 1, the TDOA τ between two receivers is the time offset between the corresponding pulse peaks. Sampling at the peak of the pulse shape is non-trivial in practise. Even with oversampling, there is still no guarantee that any of the samples will correspond to the pulse shape peak. For example, with a single sample per symbol (SPS) the smallest detectable TDOA is equal to the pulse length. Time recovery algorithms [4] are used to calculate the timing error μ between the sampling position and the peak of the pulse, see Figure 1. Commonly used SDR configurations deliver time accuracy in order of micro seconds. Our idea is to use the internally calculated μ from the time recovery algorithm. Assuming an accurate μ value, we should be able to increase the time accuracy to tens of ns . Therefore, in our system we modified the time recovery module to pass on obtained

the μ for each sample. Currently, we have a successful implementation on the N210 device and prepare for the first measurement tests. We expect time accuracy of 100 ns.

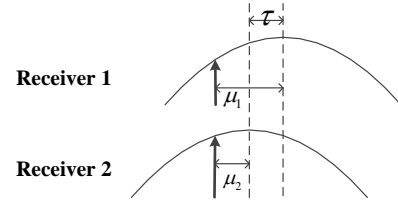


Figure 1. Signal sampling

A second approach we consider is the Generalized Cross-Correlation (GCC) method [1], which uses cross correlation between the signals received at a pair of anchors. The essence of GCC is as follows - the cross-correlation function $R_{i,j}(\tau)$ of the signals $S_i(t)$ and $S_j(t)$ at anchor nodes i and j is calculated. The TDOA is the value of the correlation coefficient that maximizes $R_{i,j}(\tau)$.

C. Indoor Interference

The above approaches deliver their best performance in Line-of-Sight (LOS) scenarios. A more complex environment such as indoor, where multipath propagation and Non-LOS (NLOS) paths are strongly present, may lead to pulse distortion or inaccurate correlation. Additionally, Inter-Symbol Interference (ISI) in GSM affects the pulse shape. All this phenomena should be addressed in our future investigations.

V. RESEARCH PERSPECTIVES

At the current stage of our work, we focus on the extracting of signal timing. Our future step are to investigate the effects of our proposed modification and interference on the achievable TDOA in a practical system. Concerning synchronisation, we already have completed an extended set of measurements and can keep satisfying synchronisation between the devices. For example, measurements show that there is a short-term clock drift of $0.208ns$ per second, which is corrected in the long term.

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